FREQUENCY ANALYSIS OF HUMAN ELECTROENCEPHALOGRAM IN THE PROCESS OF PERFORMING SPECIFIC TASKS

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THESIS

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PERFORMING SPECIFIC TASKS

by

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The frequency spectra of the EEG of subjects taken while they are engaged in mental tasks are presented and analyzed. A concurrent analog record of the subject's performance was also recorded.

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Thus the major result of the research show that preferred frequencies are generated and that these frequencies change according to the subject's activity.

Frequency Analysis of Human Electroencephalogram
In The Process Of
Performing Specific Tasks

by

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ABSTRACT

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It is shown that certain frequencies termed "preferred frequencies," appear in the spectrum picture. These frequencies are characteristic of the subject's response in the tasking situation.

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I. INTRODUCTION

A. THE RESEARCH PROJECT

Bio-Engineering at the Naval Postgraduate School is an option offered to those students who want to make a contribution between man and machine. In recent years, Bio-Engineering has thrived under the enthusiastic guidance of Professor George Marmont. Bio-Engineering offers the student a unique opportunity to study electrical engineering design problems interfacing man and his environment.

Currently, one of the projects of the Bio-Engineering research team is the analysis of the human electroencephalogram (EEG) and its applications to man and to the naval officer in particular. This analysis of EEG's can give an accurate description of a person's mental state while performing certain tasks. Using real time analysis techniques, the individual can be supplied information showing performance. This information, presented as bio-feedback, would increase the level of an individual's performance.

B. THE AUTHOR'S CONTRIBUTION

The author intends to show that while performing a task, individuals generate a specific frequency (or frequencies) in their EEG. This "preferred frequency" can then become a basic building block on which to base bio-feedback.

When reviewing previous work done by others on analysis of specific frequency generation, one finds a wealth of material pertaining to subjects in a relaxed state [Ref. 1]. Many of the studies were on subjects performing sedentary mental activity, such as listening to a series of audio signals of the same intensity and trying to detect the absence of such a signal. Another example would be studies in which the subject looked at a visual stimulus and recorded his responses. These techniques are well suited for the identification of basic frequencies such as the well known alpha, beta, delta and theta frequencies [Ref. 2] which are found in most individuals.

It becomes apparent, however, that there is a need for departure from these conventional methods of studying frequency generation. This need is for a study done with an eye toward applications in a real world environment. It will not be often that a pilot or radar operator will be found relaxing, with his eyes closed, performing his required mission. Thus, the frequencies generated while in such a relaxed state may not be applicable in the real world. However, if the pilot or radar operator is in the act of performing his mission, then the frequencies generated would be of interest and applicable. Ideally, while monitoring a radar operator searching his scope presentation, a preferred frequency should be found that indicates a high state of alertness. It is this preferred frequency identification that would open new horizons in interfacing man with machine.

Therefore, while much research has been directed toward specific frequency generation during periods while the subject is in a relaxed state, it is the author's intent to find a specific frequency while the subject is in more of a real world setting, i.e., while the subject is performing complicated tasks.

II. BACKGROUND

The fact that man's brain generates electrical activity was suspected over 100 years ago. It has been only until recently, however, with the advent of high speed real time processors that we have been able to extract useful information from this activity. It is not the intent of this author to discuss the basic EEG production but its use in evaluating a person's mental state.

Much research has been directed towards specific frequency generation during periods while the subject is in a quiet, relaxed state. There has been a paucity in research on subjects while in an active state. Tasks that require a subject to make an actual response such as press a button or push a lever have been ignored up until recently. The Bio-Engineering research team is helping to fill this void of EEG analysis during performance of tasks that eliminated the subject being in a relaxed state [Ref. 3 and 4].

III. METHODS

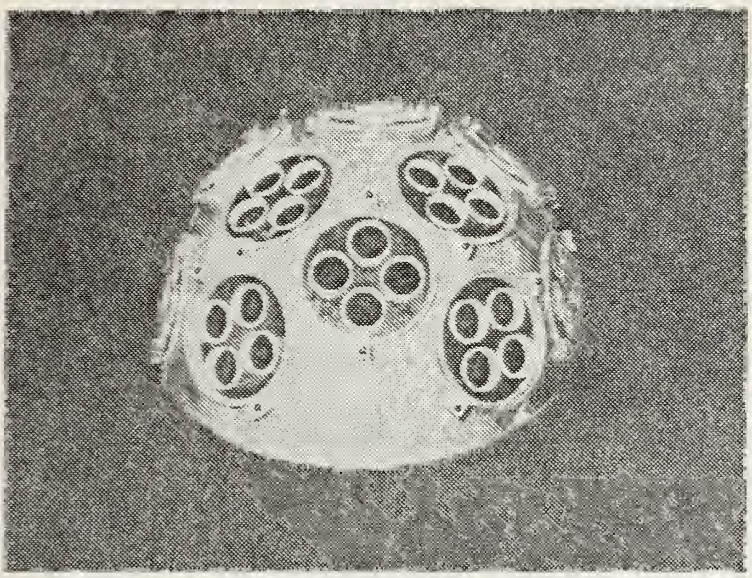
A. THE SUBJECTS

Subjects used for this project were members of the Bio-Engineering research team. All the subjects were males with no known mental dysfunction.

B. THE EQUIPMENT

Subjects were fitted with a special helmet designed by previous members of the Bio-Engineering research team at the Naval Postgraduate School. (see Fig. 1) The helmet consisted of a shell through which Beckman 2mm silver scalp electrodes fitted through slotted discs were placed over areas of interest. Sugablock, a synthetic sponge, soaked with a 0.15 molar solution of NaCl, was then placed between the electrodes and the scalp to provide good intermediate contact between the two.

The unipolar recording method was used with the reference electrode placed on the vertex. (This method was preferred because activity common to both the reference electrode and the active electrode would be rejected.) Two ground electrodes were placed on the left and right mastoid bones. When a subject's mental and physical activity level goes above the relaxed state, the need to eliminate myograms in EEG's correspondingly increases. It was found that by making the



HELMET

HELMET
WITH
ELECTRODES

Figure 1

ground plane in the mastoid area and using the vertex as a reference the likelihood of myogram pickup was reduced.

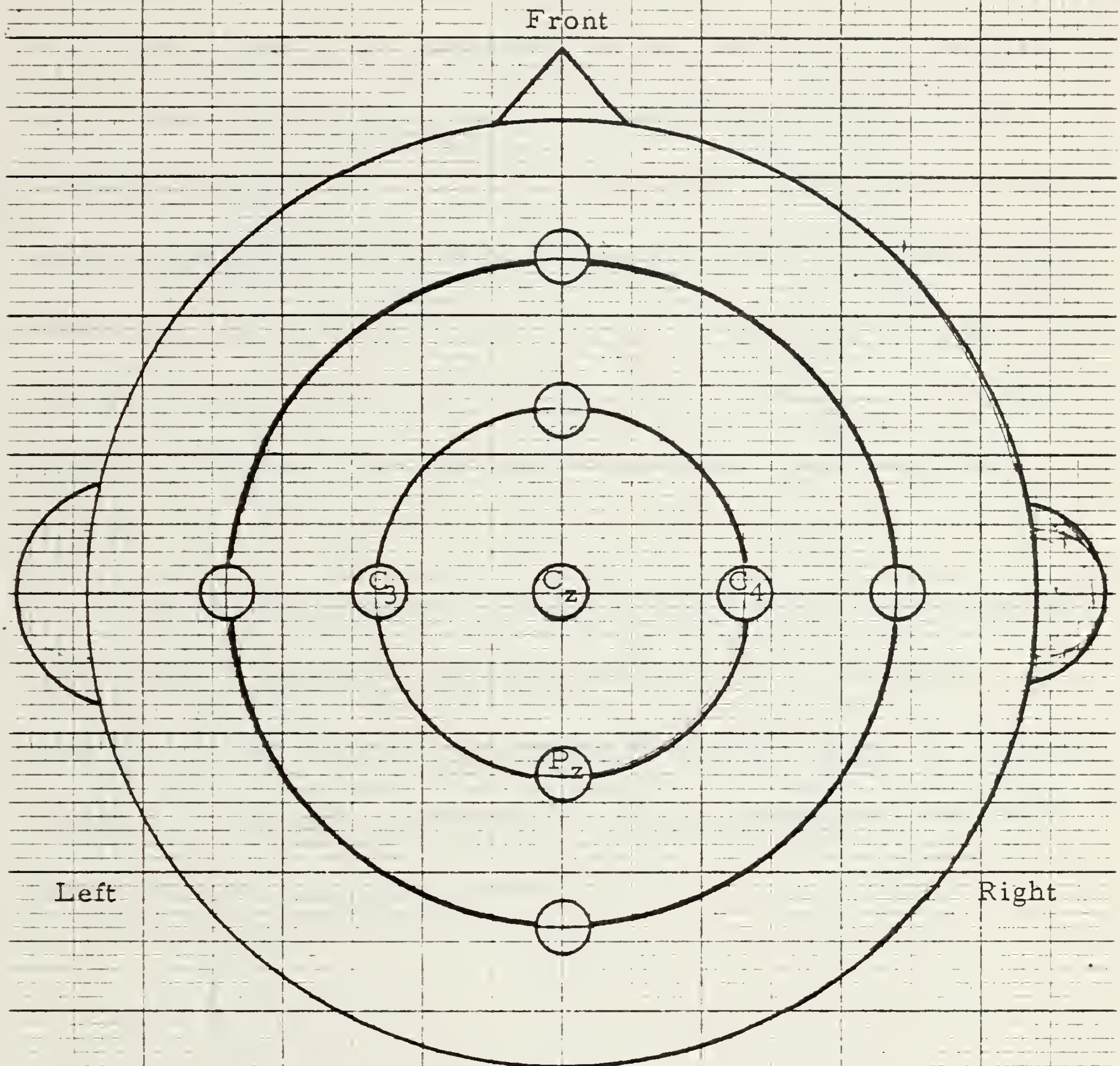
Using the International EEG system [Ref. 5] of electrode placement, three areas of the cortex were studied: the C_3 and C_4 (central) areas, corresponding to the left and right premotor areas of the cortex; and the P_z (parietal), the centerline of the parietal area. [Fig. 2]

The EEG signals were fed into differential amplifiers with a common mode rejection ratio of 90db and a gain of 4000 with low frequency cutoff of 0.1Hz. This amplified signal was then slectably filtered by a four pole Butterworth filter. The filter gain of 2.5 along with that of the amplifier combined to give a total EEG signal gain of about 10,000. This low pass anti-aliasing filter conforms with the Nyquist sampling criterion by suppressing frequencies greater than one-half the sampling rate to prevent frequency spectrum folding. The signals were converted analog to digital by a model 1923 Time/Data Signal Analyzer.

The data was then stored on a disk to allow a thorough examination at a later time.

C. THE PROGRAMMING

The basis of this preferred frequency research is the Discrete Fourier Transform (DFT). This transform was accomplished by a Digital Equipment Corporation PDP 11/40 computer and a Time/Data



Top view of electrode placement areas.

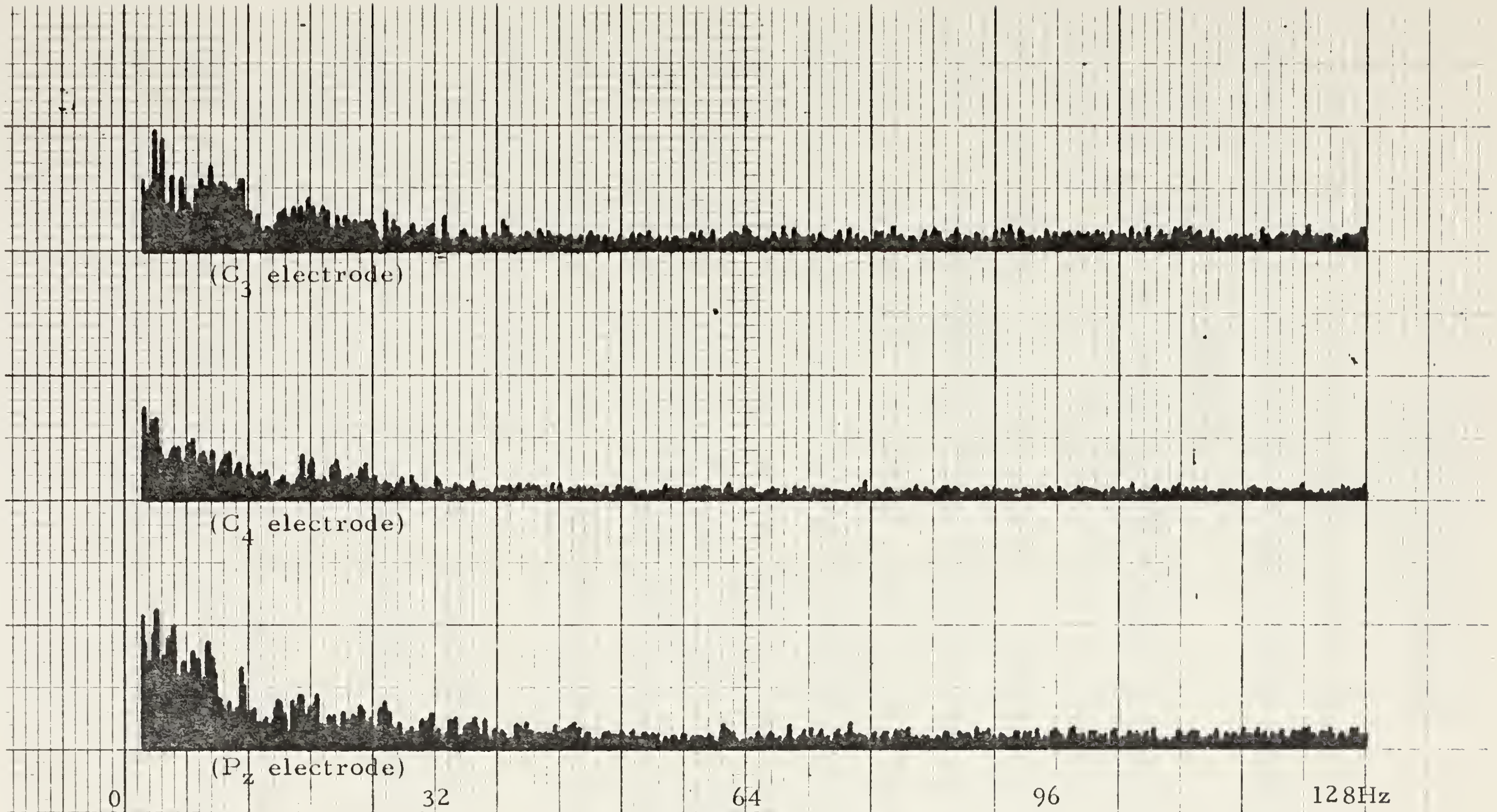
Three active electrodes over P_z, C_3 and C_4.

Reference electrode over C_z.

Figure 2

Fast Fourier Transform (FFT) micro-processor. Utilizing a program developed by previous members of the research team, a display of the DFT of the signals from the electrodes was available. A programmable rate of 256 samples per second was used giving a resultant frequency range from 0 - 128Hz. This display indicated by magnitude which frequencies were present during different mental states of the subject, for the respective electrodes. Each graph of data represents four seconds of analog signal, updated each second, i. e., the oldest second of data was deleted when a new second of data was added. (see Fig. 3.)

It was then desired to view the magnitude of the cross-spectrum of the DFT by comparing signals between different electrodes. A program was correspondingly developed to compare the P_z electrode with both the C_3 and C_4 electrodes. Also, a comparison was made between the C_3 and C_4 electrodes.



Typical display of the magnitude of the averaged (DFT) during search mode

Figure 3

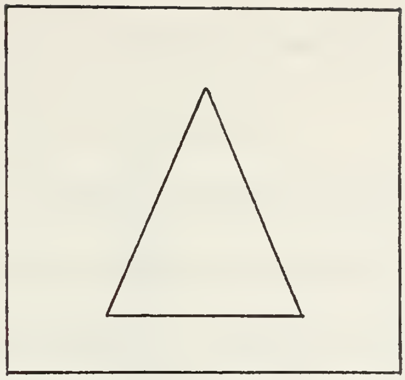
IV. TESTING PROCEDURE

The selection of the kind of task was very important. As discussed earlier, tasks to be used in this research would require mental as well as physical responses.

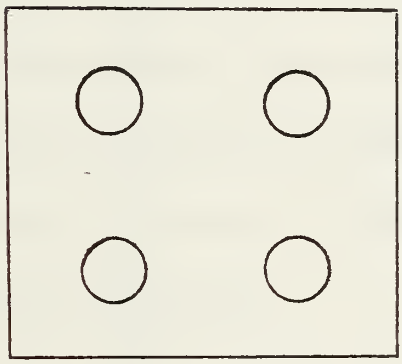
Each subject was presented with a series of stimuli which consisted of four symbols (a triangle, a circle, a plus sign and a diamond). One symbol at a time was illuminated on a screen placed in front of the subject. Directly below the screen were four response buttons, each button corresponding to one symbol. (see Fig. 4) The basic task required the subject to press the correct response button for each symbol as it appeared on the screen. If the correct button was depressed, then another symbol would appear. If not, the original symbol would remain until the correct button was depressed. Thus, each subject responded at his own pace since the symbol presented changed only after a correct response.

The symbols appeared one at a time according to a pre-set pattern. This symbol-correct response pattern could be changed during the runs on each subject.

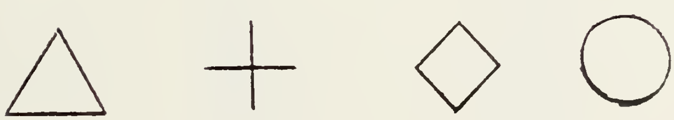
This task allowed the author to investigate two different mental states of the subject. The first state was called the "search mode" because the subject was learning the correct response pattern. The



Illuminated screen display



Response Buttons

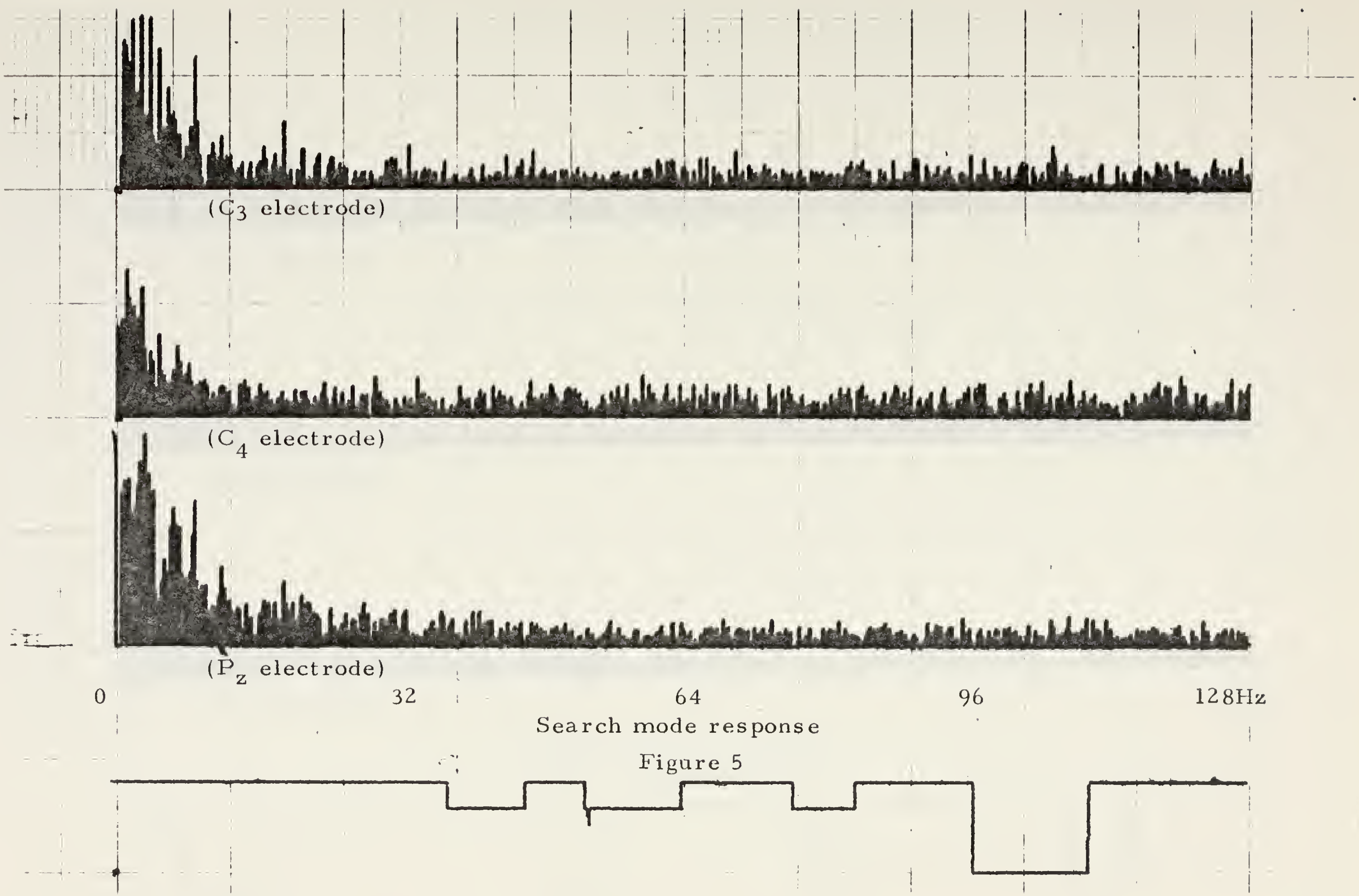


Symbols

Figure 4

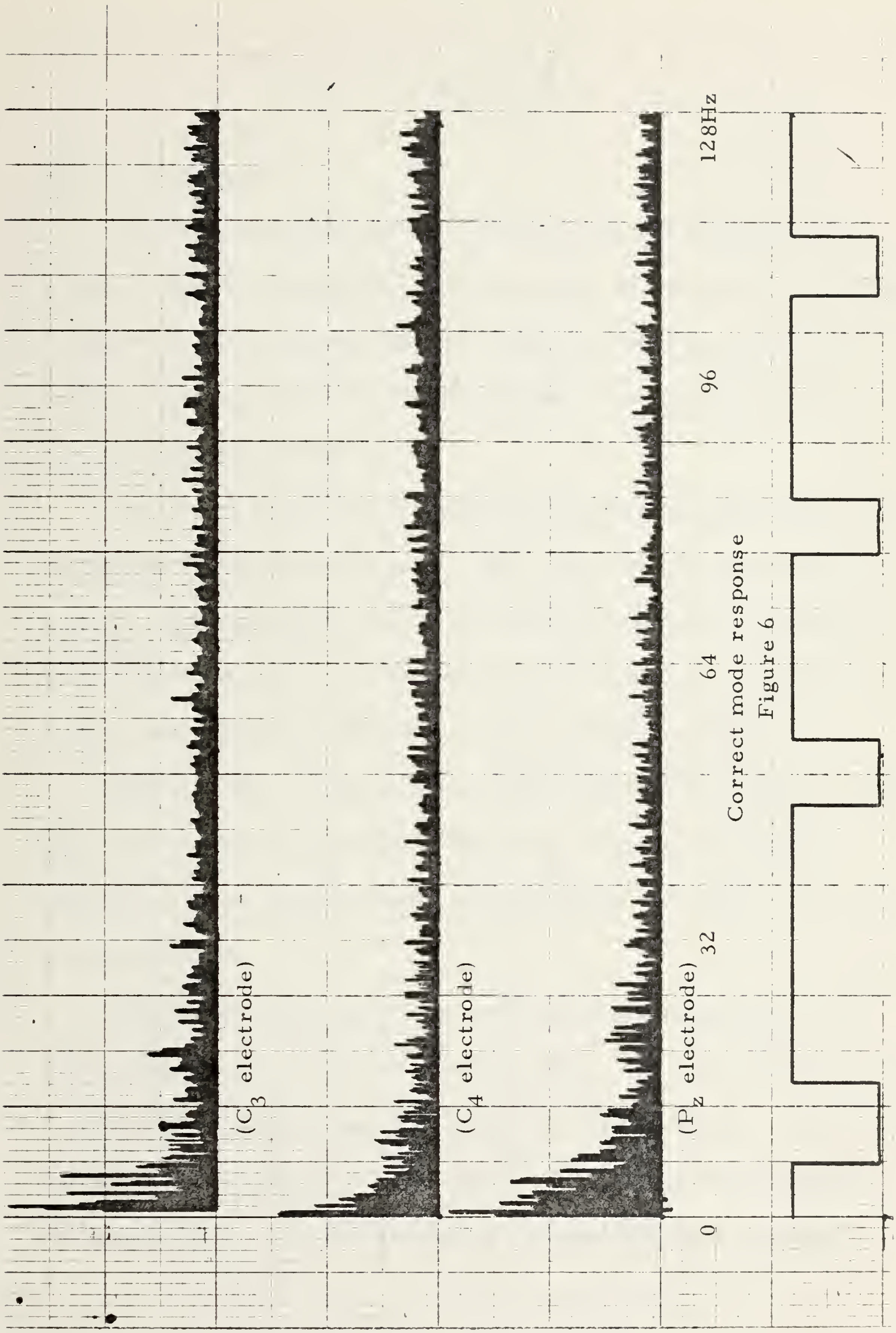
second state was the "correct mode" since the subject had learned the pattern. Identification of frequencies generated in these two modes was the goal of this investigator.

In order to have an analog record of the search/correct modes of operation the ability to simultaneously have a display in time along with the corresponding frequency domain was essential. As a result, Figures 5 and 6 show this relationship. The top three traces show the DFT of the EEG from 0 - 128Hz and the bottom trace shows the response record. The small depressions in the response record indicate incorrect responses, while the large depressions indicate correct responses. The DFT traces were then averaged over periods corresponding to the search/correct modes. The figures showing the average DFT all have the fourth trace deleted.



Search mode response

Figure 5



Correct mode response
Figure 6

V. RESULTS

A. TECHNIQUES

The first recording was taken with the subject sitting upright, relaxed, with his eyes open. This recording of data was the baseline displayed in the frequency domain. This was used as a reference level to be compared later with the subject's performance in the search and correct modes.

The second series of recordings was taken when the subject was initially presented with the task. The subject was given no practice periods. This initial run would show what frequencies were being generated while in the search mode of operation, i. e., while the subject was learning the symbol-correct response pattern.

Following this run the subject, having learned the pattern, would then exhibit the correct mode. The pattern sequence would then be changed so as to make the subject repeat these two modes. This was the third series.

Using the baseline record as reference and comparing it with the records of the search and correct modes, one could identify those frequencies present during the search and correct modes. Also, frequencies that appeared in the initial subject runs and the last of the task periods could be correlated. It was found that when the

subject was first presented with the task many frequencies not present in the baseline appeared. These frequencies were not present in later runs on the same subject. This "new game" frequency generation can be attributed to the fact that the subject was in a new and unusual environment. These "new game" frequencies disappeared in later stages of the run after the subject became accustomed to the procedure. However, in both the initial and later runs, frequencies were identified that can be termed specific for that mode of operation, i.e., search or correct.

Averaging of the DFT was used to eliminate spurious frequencies that might have been generated and therefore would not be related to the tasking process.

In an effort to further identify preferred frequencies during the different modes of operation, a cross-spectrum was performed on the DFT and then averaged. This was accomplished by crossing the signal from the P_z electrode with the C_3 electrode and then with the C_4. Also, the C_3 electrode was crossed with the C_4.

The magnitude of the cross-spectral response from the respective electrodes pairs was then averaged. This cross-spectrum was intended to confirm the frequencies identified during the averaging method.

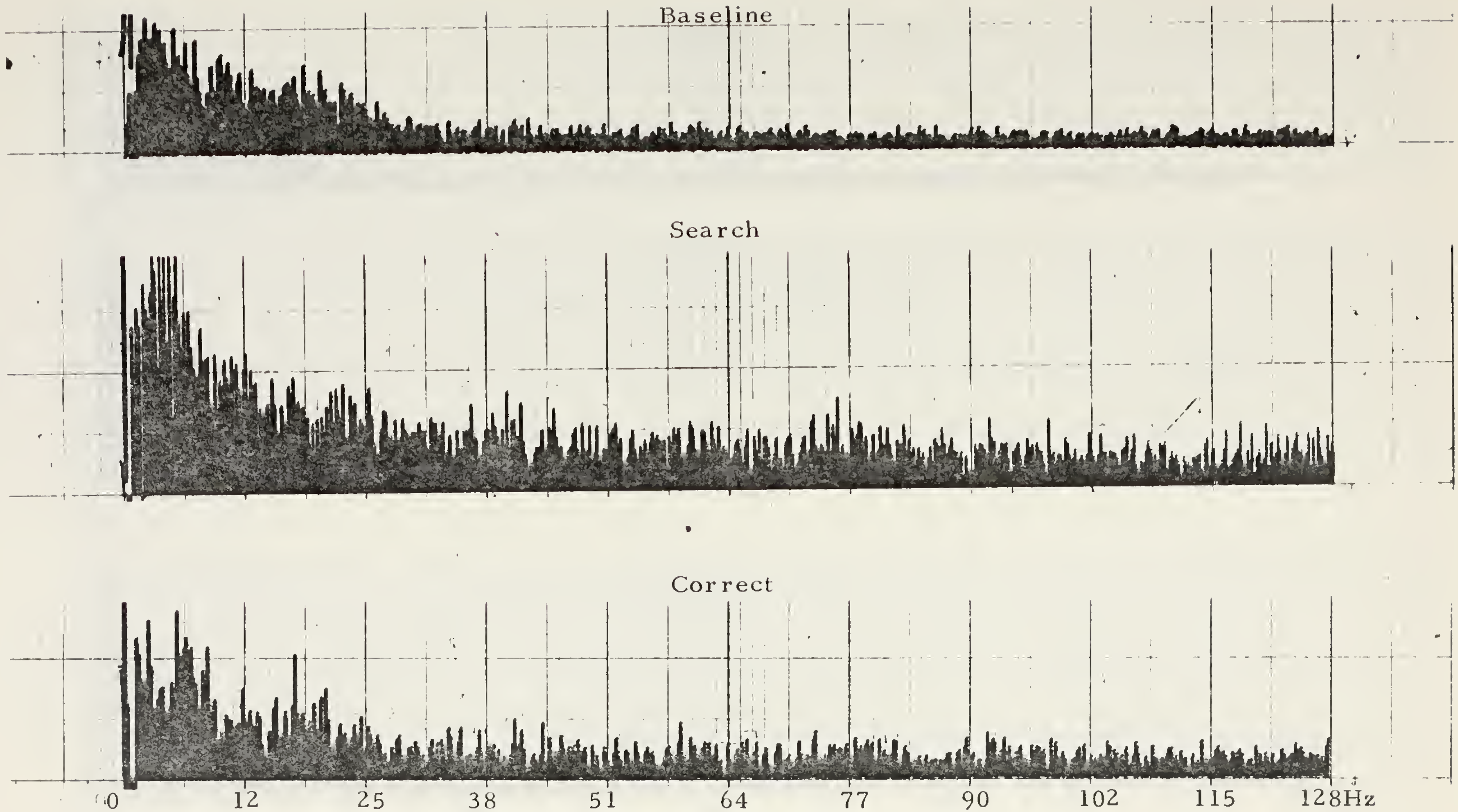
B. FINDINGS

The frequencies produced while performing the task varied from individual to individual as expected. However, during the search mode three distinct frequency ranges were common to all subjects: 19 - 23Hz, 32 - 42Hz and 64 - 110Hz. These ranges seem to indicate that the subject knows he is under a test situation and some response is required. Similar results have been reported by previous members of the research team. [Ref. 4]

It was during the correct mode, when the subject had learned the response pattern, that an interesting change occurred. The search mode frequencies became diminished in magnitude and new frequencies appeared. particularly in the 25 - 35Hz range. This change would indicate that the subject is now out of the searching process and has learned the pattern.

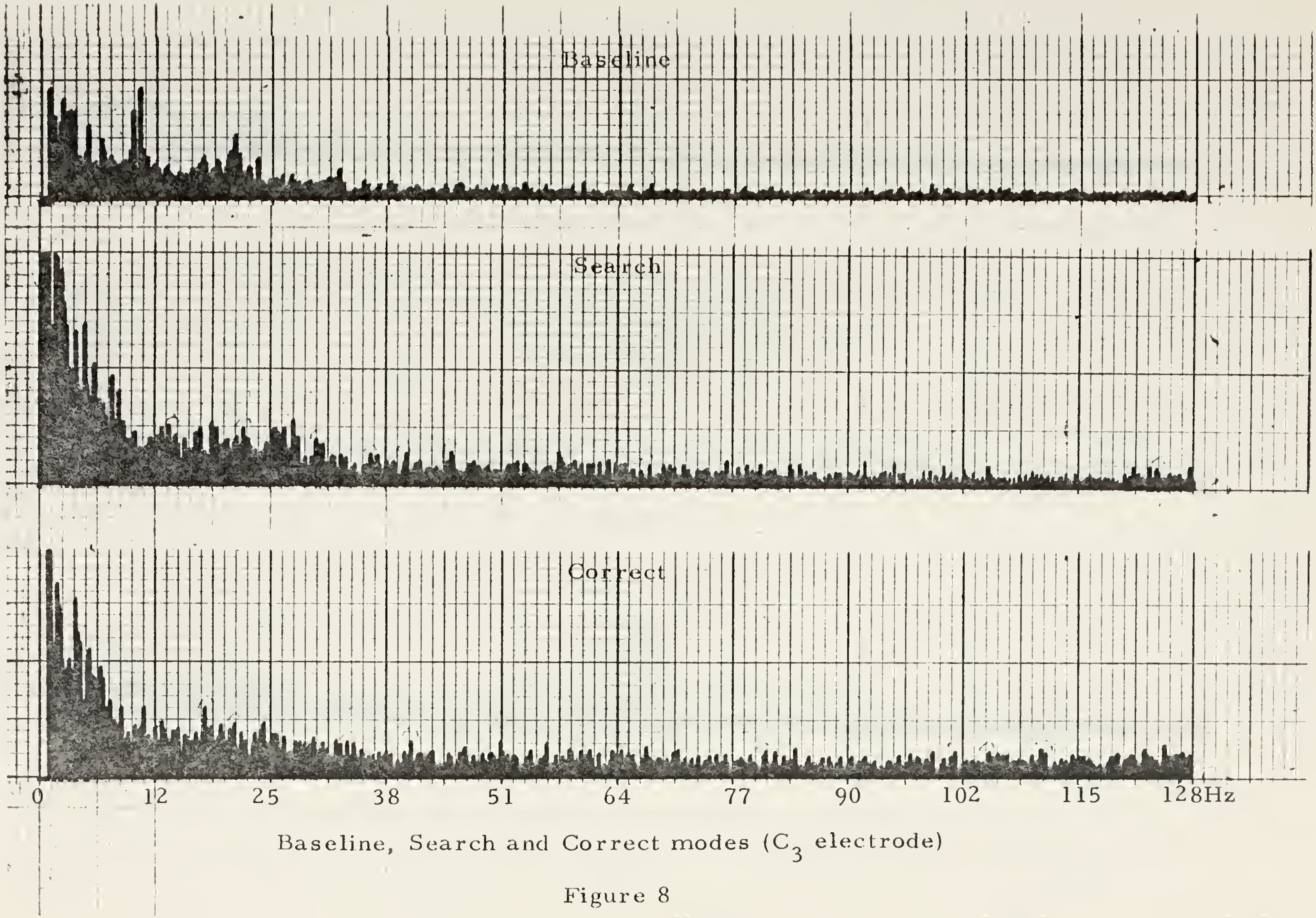
Figures 7, 8 and 9 are a graphic representation of the above findings. They show a baseline, a search mode response and a correct mode response for each electrode placement. (see Fig. 2) When comparing the search mode response frequencies with the baseline, one can see the increased magnitude of the frequencies. By then comparing the correct mode one can see how the magnitude of the search mode frequencies diminishes in the correct mode and how new frequencies in the 25 - 35Hz range appear.

All three figures represent data on the same subject. The frequencies present in the search/correct modes were present



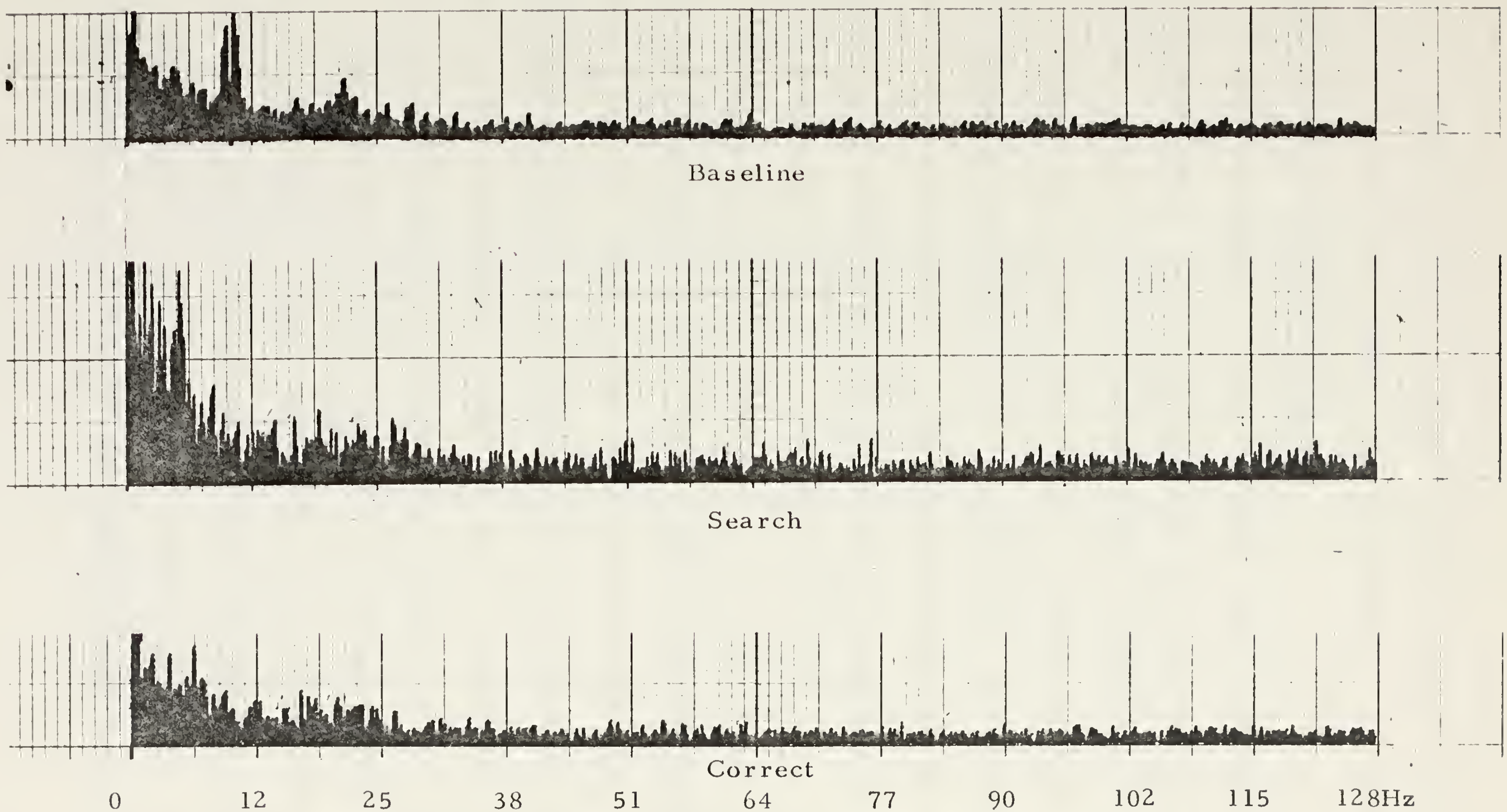
Baseline, Search and Correct modes (P_z electrode)

Figure 7



Baseline, Search and Correct modes (C_3 electrode)

Figure 8



Baseline, Search and Correct modes (C_4 electrode)

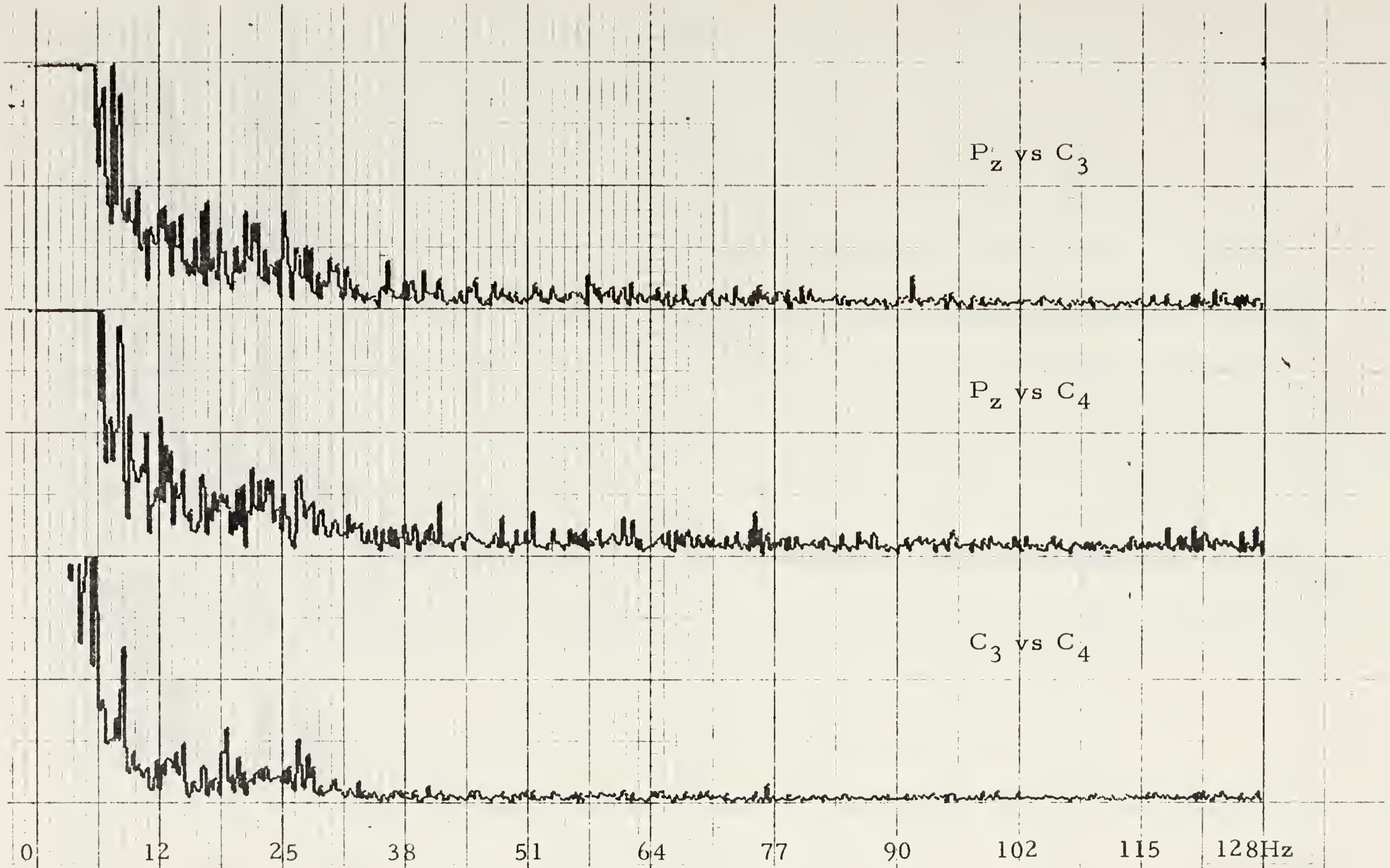
Figure 9

throughout the entire testing procedure, i.e., the specific frequencies for the respective modes occurred on each run made on the subject over a period of forty minutes. These last figures and findings were typical of the average DFT method.

It became apparent that these findings needed to be substantiated by another means. The cross-spectrum was taken with the following results. First, as in the averaging method, frequencies in the 64 - 110Hz range showed a marked increase when the P_z electrode was compared to both the C_3 and C_4 electrodes. But there was no such increase between the C_3 and C_4 electrodes during the search mode. Also, during this mode there was an increase in the 12 - 20Hz range for the P_z - C_3 and P_z - C_4 pairs. [Fig. 10]

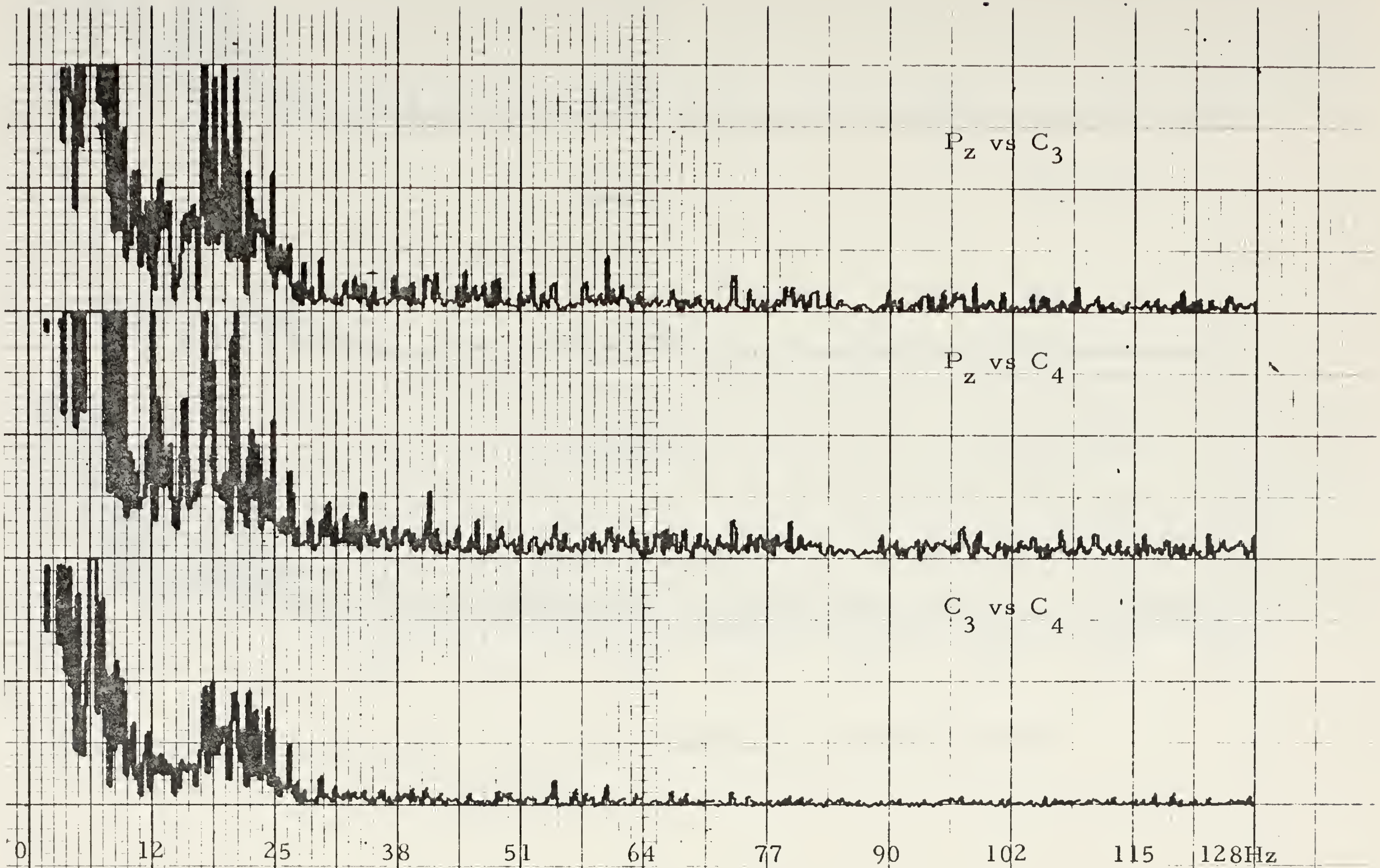
Secondly, during the correct mode of operation the cross-spectrum showed an increase in the 24 - 28Hz range not found in the search mode. [Fig. 11] This increase was found when comparing the P_z electrode with the C_3 and C_4 electrodes. As can be seen, there was no decrease in magnitude between the search and correct modes as contrasted with what was found in the averaging results. [Fig. 12]

Again there was a distinctive change in preferred frequencies generated when the subject was learning the pattern and when he had learned it. The cross-spectrum technique was felt to be more informative because it possibly indicates that the brain was doing parallel processing over an extended area. Comparing an area of



Cross-spectrum during search mode

Figure 10



Cross-spectrum during correct mode

Figure 11

Composite cross-spectrum: Baseline, Search and correct modes

Figure 12

cortex generating a particular frequency or frequencies, with another area not exhibiting the same frequencies there would be no results in the cross-spectrum, i.e., the magnitude of the cross-spectrum would approach zero.

VI. DISCUSSION

This research substantiates the idea that preferred frequencies occur in the human EEG during a specific task. Not only were frequency ranges that could be identified as particular to the learning process present during the learning of a pattern, but also different frequencies were present after the subject had learned the pattern.

This difference in frequency generation is significant. It suggests that discrete frequency ranges are indicative of particular mental states of subjects studied while performing tasks that require mental as well as physical decisions. Caution must be used in expanding these results for identification of preferred frequencies for all tasks. This research was based on one tasking procedure. It remains for future investigators in this field to present subjects with a variety of tasks.

Interestingly, during the course of this research, a previous theory postulated by the Bio-Engineering research team was confirmed. Some earlier studies showed that EEGs were like fingerprints, i. e., subjects produced their own distinctive EEGs. The same was true in this study of EEGs in the frequency spectrum. No two individuals had exact duplication of frequencies. An individual, however, did have distinct frequencies that could be identified as those particular to that person. Thus the author was able to identify subjects by these 'fingerprint' frequencies.

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